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# The environmental Kuznets curve and the role of coal consumption in India: Cointegration and causality analysis in an open economy

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ABSTRACT

This study investigates the dynamic relationship between coal consumption, economic growth, trade openness and $CO_2$ emissions in case of India. In doing so, Narayan and Popp, Journal of Applied Statistics 2010; 37:1425–1438, structural break unit test is applied to test the order of integration of the variables. Long run relationship between the variables is tested by applying the ARDL bounds testing approach to cointegration developed by Pesaran et al. Journal of Applied Econometrics 2001; 16:289–326.

The results confirm the existence of cointegration for long run between coal consumption, economic growth, trade openness and $CO_2$ emissions. Our empirical exercise indicates the presence of environmental Kuznets curve (EKC) in long run as well as in short run. Coal consumption as well as trade openness contributes to $CO_2$ emissions. The causality analysis reports the feedback hypothesis between economic growth and $CO_2$ emissions and same inference is drawn between coal consumption and $CO_2$ emissions. Moreover, trade openness Granger causes economic growth, coal consumption and $CO_2$ emissions.



**Contents**



## 1. Introduction

The Kyoto Protocol requires that industrialized countries reduce their collective emissions of greenhouse gasses by 5.2% of 1990 levels by the period 2008–2012. The country-specific targets in the Kyoto Protocol may be difficult for some nations to achieve. Developing countries, including India, have absolved of any responsibility towards reducing emissions in the first commitment period, that is, 2008–2012, of the Kyoto Protocol. However, India estimates a 24% cut by 2020 in its carbon intensity i.e., the amount of carbon dioxide emitted for each unit of GDP, compared with 2005 levels, and by 2030, it estimates it could achieve a reduction in its carbon emissions by 37% from 2005 levels, according to provisional government figures (The Indian Express [71]).

Theoretically, the environmental Kuznets curve (EKC) hypothesis postulates the existence of an inverted-U shape relationship between real GDP per capita and measures of environmental degradation such as $SO_2$ and/or $CO_2$ emissions. However, the empirical evidences, either using time series and/or pooled data of a group of countries, on the EKC hypothesis vary from country to country, instead. Further, the results are not uniform across pollutants. This has created tow problems being faced by environmental

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policy makers: to ensure that useful knowledge informs policy (without being misused and/or distorted) and to understand how to respond to this knowledge (Boehmer-Christiansen [1]). However, in the present context we have limited ourselves to provide evidence of the EKC hypothesis for India. Our contribution lies, particularly in two directions. First, we employed the ARDL method which is amenable for short time series data as in this paper and second, we provide empirical evidence of the EKC by incorporating coal consumption and trade as additional determinant of $CO_2$ emissions in case of India.

The rational for selecting India for our analysis is that it has implemented a variety of programs and policy initiatives since the introduction of the National Forest Policy in 1988. India has become one of the fast growing countries next to China. However, in the same time consumption of coal has increased rapidly which was 35.55 mote in 1965 has reached the height of 249.86 mote in 2009. The close relationship between coal consumption and economic growth of India is evident from following Fig. 1. Further if we see the relationship between percentage growth rates of GDP and coal consumption, we find that recently percentage growth rate in the coal consumption is more than twice of the percentage GDP growth rate. This situation is evident in Fig. 2.

With this background we set objective to test the environmental Kuznets curve hypothesis (EKC) in augmented equation framework. According to the EKC hypothesis environmental degradation increases at initial level of economic growth and then starts to decrease at a higher level of economic growth. Hence, the relationship between measure of environmental degradation, (in our case it is $CO_2$ emissions) and measures of economic growth (in our case it is measured by real GDP per capita) is the inverted-U shaped curve. The objective of present study is to investigate the EKC for the Indian economy over the period of 1966–2011. In addition, we also include coal consumption and trade openness.

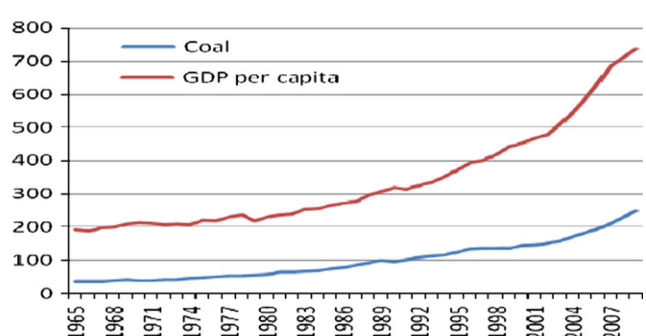


**Fig. 1.** Coal consumption and GDP per capita.

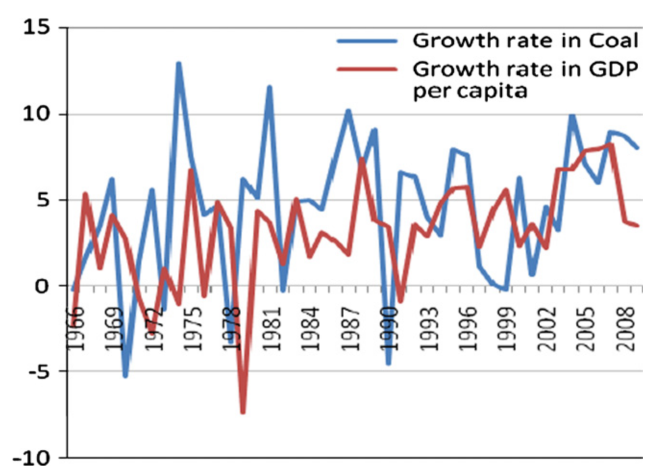


**Fig. 2.** Percentage growth rate in coal consumption and GDP.

The rest of the paper consists of: Section 2 reviews a selected literature encompassing the EKC and the variables listed above, Section 3 has the theoretical and the econometric model including the ARDL estimation strategy. The empirical results are reported in Section 4 followed by the conclusion and policy implications.

## 2. Literature review

There has been increasing attention on the impact of economic growth on environment degradation since the last few decades of the previous century. The pioneering attempt in this area was made in the early 1990s by Grossman and Krueger [2,3] which investigated the environmental impacts of the North American Free Trade Agreement. Their study postulated, estimated and ascertained an inverted-U shaped relationship between measures of several pollutants and real GDP per capita which was, contemporaneously, confirmed by Shafik and Bandyopadhyay [4] and Panayotou [5]. Theoretically, the EKC does not only depend on levels of per capita GDP, but also on a series of factors causing changes in economic growth that can affect environment. In general, economists analyze mechanisms behind the EKC by examining scale effect, structural effect and technique effect (Song et al. [6]). However, few scholars (for example, Panayotou [5]) believe that EKC is caused by up-gradation from the adjustment of economic structure. According to the structural effect hypothesis (Stern [7]) economic development passes through the various states starting form preliminary, rapid-development and high-grade, industrial structure first upgrades from agriculture to a high-pollution industry, finally turns to information concentrated industry, which leads to the improvements in environmental quality. However, as Stokey [8] pointed out, due to the technique effect economic growth can break through one threshold point after arriving at a certain stage of economic development. Hence, at a low income level, only the high pollution technique can be used, but once leaping over the threshold point of economic development, cleaner technologies can be adopted which lowers the degradation in the environmental quality. Further, some scholars attribute the demand factors to the cause of EKC (for example, Lopez [9]), which asserts that demand for a clean environment will be increased over the real income per capita. Giving the importance of scale effect, Andreoni and Levinson [10] suggested that in the static model of single department, the EKC can be derived technically, only if pollution control is increasing in scale.

Further, Suri and Chapman [11] bring the contribution of industrial products of the imports and exports to industrial products of national production into the analytical framework of the EKC. That is to say, the low emissions correspond to the growth of industrial products of the imports, while the high emissions correspond to that of the exports. This implies that there is a strong relationship between trade and environmental quality, so the evolution of environmental quality can be predicted effectively. The empirical studies of EKC started by Grossman and Krueger [2] and followed by Lucas et al. [12], Wyckoff and Roop [13], Suri and Chapman [11], Heil and Selden [14], Friedl and Getzner [15], Stern [7], Nohman and Antrobus [16], Dinda and Coondoo [17] and Coondoo and Dinda [18] but presented mixed empirical evidence on the validity of EKC. Song et al. [6], Dhakal [19], Jalil and Mahmud [20] and, Zhang and Cheng [21] supported the existence of EKC in China. The findings of Fodha and Zaghdoud [22] revealed the existence of EKC between the $SO_2$ emissions and economic growth but not for the $CO_2$ emissions in

Tunisia. In contrast, Akbostancl et al. [23] did not support the existence of EKC in Turkey and same conclusion was drawn by Saboori et al. [64] for Indonesia. They argued that $CO_2$ emissions are automatically reduced due to the rapid pace of economic growth.

Recent literature documented alliance of economic growth with energy consumption and environmental pollution to investigate the validity of EKC. The relationship between economic growth, energy consumption and $CO_2$ emissions have also been researched extensively both in the country case and panel studies. For example, Ang [24] found stable long run relationship between economic growth, energy consumption and $CO_2$ emissions for French economy while Ang [25] also got similar results for Malaysia. Ang [24] showed that causality is running from economic growth to energy consumption and $CO_2$ emissions in the long run but energy consumption Granger-causes economic growth in the short run. In case of Malaysia, Ang [25] reported that output increases $CO_2$ emissions and energy consumption. Ghosh [26] documented that no long run causality between economic growth and $CO_2$ emissions and in the short run, bidirectional causality exists in India. On contrary, Tiwari [66] noted unidirectional causality running from $CO_2$ emissions to economic growth and $CO_2$ emissions and energy consumption and $CO_2$ emissions Granger cause each other. In case of Indonesia, Hwang and Yoo [69] noted bidirectional causality between energy consumption and $CO_2$ emissions in long run but in short run, energy consumption and $CO_2$ emissions are cause of economic growth. Latter on, Uddin et al. [70] investigated the relationship between energy consumption, economic growth, trade openness and $CO_2$ emissions in case of Srilanka. Their results found that economic growth Granger causes energy consumption and $CO_2$ emissions.

For the panel studies, Apergis and Payne [27] investigated this relationship for six Central American economies using panel VECM. It is evident that energy consumption is positively linked with $CO_2$ emissions and EKC hypothesis has been confirmed. Lean and Smyth [28] and Apergis and Payne [29] reached the same conclusion for the case of ASEAN countries and Commonwealth of Independent States, respectively. Narayan and Narayan's [30] empirical evidence also validates the EKC hypothesis for 43 low income countries. In addition, Lean and Smyth [28] noted a long run causality running from energy consumption and $CO_2$ emissions to economic growth but in short span of time, energy consumption Granger causes $CO_2$ emissions. On the other hand, Apergis and Payne [29] found that energy consumption and economic growth Granger causes $CO_2$ emissions while bidirectional causality is found between energy consumption and economic growth; and between energy consumption and $CO_2$ emissions. Chen [31] explored this issue to Chinese provinces and documented that industrial sector's development is linked with increase of $CO_2$ emissions due to energy consumption. Similarly, Shiyi [32] investigated the relationship between industrial sector's development and $CO_2$ emissions using Chinese provincial data and concluded that industrial development increases $CO_2$ emissions. Pao and Tsai [33], Ozturk and Acaravci [34] and, Acaravci and Ozturk [35] also validated the existence of the EKC in case of BRIC, Turkey and Demark and Italy, respectively. In case of Pakistan, Nasir and Rehman [36] and, Shahbaz et al. [37] reported that the EKC exists while a rise in economic growth and energy consumption is linked with an increase in energy pollutants. Iwata [38] investigated the empirical existence of the EKC in 28 countries adding Pakistan. They corroborated the existence of the EKC by nuclear energy consumption taking into account. Saboori et al. [65] unveiled that long run as well as short run EKC exists in case of Malasia. Unidirectional causality from economic growth to $CO_2$ emissions further malidates the existence of KEC for Malaysian economy. Yeh [67] used the quintiles regressions using the data of developed and developed countries and reported the existence of EKC by controlling other macroeconomic variables. In case of Romania, Shahbaz et al. [68] confirmed long run relationship between economic growth, energy consumption and energy pollutants. Their empirical evidence also found that environmental Kuznets curve (EKC) exist both in long-and-short runs. Moreover, energy consumption is major contributor to energy pollutants. Democratic regime shows her significant contribution to decline $CO_2$ emissions through effective implementation of economic policies and financial development improves environment i.e., reduces $CO_2$ emissions by redirecting the resources to environment friendly projects.

The relationship between trade openness and environmental degradation has also been investigated empirically. Grossman and Krueger [2]) argued that environmental effect of international trade depends on the policies of an economy. There are two schools of thought about the impact of international trade on $CO_2$ emissions. One argued that trade openness provides an offer to each country to have access to international market which enhances the market share among countries. This leads the competition among the countries and increases the efficiency of using scarce resources and encourages importing cleaner technologies to decline $CO_2$ emissions (e.g., Runge [39] and Helpman [40]). Other group probed that natural resources are depleted due to international trade. This depletion of natural resources raises $CO_2$ emissions and causes environment quality worsened (e.g., Schmalensee et al. [41]; Copeland and Taylor [42]; Chaudhuri and Pfaff [43]). In country case studies, Machado [44] indicated positive link between foreign trade and $CO_2$ emissions in Brazil. Mongelli et al. [45] concluded that pollution haven hypothesis is existed in Italy. Halicioglu [46] added trade openness to explore the relationship between economic growth, $CO_2$ emissions and energy consumption for Turkey. The result showed that trade openness is one of main contributor to economic growth while income raises the levels of $CO_2$ emissions. Finally, Jayanthakumaran et al. [47] probed the relationship between economic growth, energy consumption, trade openness and $CO_2$ emissions in case of India and China. Their empirical evidence confirmed the validation of EKC in both countries.

## 3. Modeling, empirical strategy and data collection

The dynamic relationship between income, coal consumption and $CO_2$ emissions is investigated by including trade openness as potential determinant to $CO_2$ emissions. For this purpose, we followed the empirical model applied by Ang [25,26] for France and Malaysia, Soytas et al. [48] for United States, Jalil and Mahmud [20] for China, Halicioglu [46] for Turkey, and Shahbaz et al. [37] for Pakistan. We use coal consumption as an indicator of energy rather than energy consumption. More than 50% energy demand in India is fulfilled from coal consumption. Following Shahbaz et al. [37], we converted all the series into natural logarithms to obtain efficient and consistent results. The relation is specified as follows:

$$CO_{2,t} = f\left(Y_t, Y_t^2, C_t, TR_t\right) \tag{1}$$

In the log-linear form the specification is written as:

$$\ln CO_{2,t} = \phi_1 + \phi_2 \ln Y_t + \phi_3 \ln Y_t^2 + \phi_4 \ln C_t + \phi_5 \ln TR_t + \mu_t \tag{2}$$

where, $CO_2$ denotes carbon emissions per capita (in kt); $C$ is coal consumption per capita; $Y$ and ($Y^2$) mentions real GDP per capita and its square, respectively. TR is trade openness [(exports+imports)/GDP)] per capita $\mu$ is a random error term. Following the EKC hypothesis we expect that $\varphi_2 > 0$ and $\varphi_3 < 0$. The use of coal

is detrimental for environment and it is expected that $\phi_4>0$. The impact of trade openness on $CO_2$ emissions can be positive or negative. This implies that $\phi_5<0$ if government enforces environmental laws, and makes possibility to import of environment friendly capital and technology to be used in production process. But Grossman and Krueger [2,3] argued that if emissions might be generated due to relocation of polluting industries from developed economies, a practice known in the literature as the 'safe-haven hypotheses' the $\phi_5>0$.

We applied a recent unit root test developed by Narayan and Popp [49] to attain efficient and consistent empirical evidence about the integration order of the variables. This test incorporates about two structural breaks stemming in the series which is based on two regression equations of the form as follows:

$$y_t^{M1}=\rho y_{t-1}+\alpha_1+\beta^* t+\theta_1 D(T'_B)_{1,t}+\theta_2 D(T'_B)_{2,t} +\delta_1 DU'_{1,t-1}+\delta_2 DU'_{2,t-1}+\sum_{j=1}^{k}\beta_j\Delta y_{t-j}+e_t \quad (3)$$

$$y_t^{M2}=\rho y_{t-1}+\alpha^*+\beta^* t+\kappa_1 D(T'_B)_{1,t}+\kappa_2 D(T'_B)_{2,t} +\delta_1^* DU'_{1,t-1}+\delta_2^* DU'_{2,t-1}+\gamma_1^* DT'_{1,t-1}+\gamma_2^* DT'_{2,t-1} +\sum_{j=1}^{k}\beta_j\Delta y_{t-j}+e_t \quad (4)$$

where $e_t$ is a white noise process, such that $e_t\sim NIID(0,\sigma^2)$, $D(T'_B)_{i,t}=1(t=T'_{B,i}+1)$, $i=1,2$, $DU'_{i,t}=1(t>T'_{B,i})$, $DT'_{i,t}=1(t>T'_{B,i})(t-DT'_{B,i})$, $T'_{B,i}$, $i=1, 2$, denote the true break dates. Eqs. (3) and (4) are IO-type test regression for M1 and M2, respectively. The unit root null hypothesis of $\rho=1$ is tested against the alternative hypothesis of $\rho<1$ by using the $t$-statistics of $\hat{\rho}$. Since it is assumed that true break dates are unknown, $T'_{B,i}$ in Eqs. (3) and (4) has to be substituted by their estimates $\hat{T}_{B,i}$, $i=1, 2$, in order to conduct the unit root test. We used a sequential procedure following Narayan and Popp [49] to attain $\hat{T}_{B,i}$, $i=1, 2$.

We apply the autoregressive distributed lag model or the ARDL bounds testing approach to cointegration. The ARDL bounds testing approach to cointegration is preferred due to its certain advantages over traditional cointegration approaches. For example, the ARDL bounds testing is flexible regarding the integrating order of the variables whether variables are found to be stationary at I(1) or I(0) or I(1)/I(0)[1]. The Monte Carlo investigation shows that this approach is superior and provides consistent results for small sample (Pesaran and Shin [50]). Moreover, a dynamic unrestricted error correction model (UECM) can be derived from the ARDL bounds testing through a simple linear transformation. The UECM integrates the short run dynamics with the long run equilibrium without losing any information for long run. The empirical formulation of the ARDL bounds testing approach to cointegration is given below:

$$\Delta \ln CO_t^2=\alpha_1+\alpha_T T+\alpha_{CO^2}\ln CO_{t-1}^2 +\alpha_Y \ln Y_{t-1}+\alpha_{Y^2}\ln Y_{t-1}^2+\alpha_C \ln C_{t-1}+\alpha_{TR}\ln TR_{t-1} +\sum_{i=1}^{p}\alpha_i\Delta\ln CO_{t-1}^2+\sum_{j=0}^{q}\alpha_j\Delta\ln Y_{t-j}+\sum_{k=0}^{r}\alpha_k\Delta\ln Y_{t-1}^2 +\sum_{l=0}^{s}\alpha_l\Delta\ln C_{t-l}+\sum_{m=0}^{t}\alpha_m\Delta\ln TR_{t-m}+\mu_t \quad (5)$$

$$\Delta\ln Y_t=\alpha_1+\alpha_T T+\alpha_{CO^2}\ln CO_{t-1}^2+\alpha_Y\ln Y_{t-1} +\alpha_{Y^2}\ln Y_{t-1}^2+\alpha_C\ln C_{t-1}+\alpha_{TR}\ln TR_{t-1}+\sum_{i=1}^{p}\beta_i\Delta\ln Y_{t-i} +\sum_{j=0}^{q}\beta_j\Delta\ln CO_{t-1}^2+\sum_{k=0}^{r}\beta_k\Delta\ln Y_{t-1}^2+\sum_{l=0}^{s}\beta_l\Delta\ln C_{t-l} +\sum_{m=0}^{t}\beta_m\Delta\ln TR_{t-l}+\mu_t \quad (6)$$

$$\Delta\ln Y_t^2=\alpha_1+\alpha_T T+\alpha_{CO^2}\ln CO_{t-1}^2+\alpha_Y\ln Y_{t-1} +\alpha_{Y^2}\ln Y_{t-1}^2+\alpha_C\ln C_{t-1}+\alpha_{TR}\ln TR_{t-1}+\sum_{i=1}^{p}\beta_i\Delta\ln Y_{t-1}^2 +\sum_{j=0}^{q}\beta_j\Delta\ln CO_{t-1}^2+\sum_{k=0}^{r}\beta_k\Delta\ln Y_{t-k}+\sum_{l=0}^{s}\beta_l\Delta\ln C_{t-l} +\sum_{m=0}^{t}\beta_m\Delta\ln TR_{t-m}+\mu_t \quad (7)$$

$$\Delta\ln C_t=\alpha_1+\alpha_T T+\alpha_{CO^2}\ln CO_{t-1}^2+\alpha_Y\ln Y_{t-1} +\alpha_{Y^2}\ln Y_{t-1}^2+\alpha_C\ln C_{t-1}+\alpha_{TR}\ln TR_{t-1}+\sum_{i=1}^{p}\vartheta_i\Delta\ln C_{t-i} +\sum_{j=0}^{q}\vartheta_j\Delta\ln CO_{t-1}^2+\sum_{k=0}^{r}\vartheta_k\Delta\ln Y_{t-k}+\sum_{l=0}^{s}\vartheta_l\Delta\ln Y_{t-1}^2 +\sum_{m=0}^{t}\vartheta_m\Delta\ln TR_{t-m}+\mu_t \quad (8)$$

$$\Delta\ln TR_t=\alpha_1+\alpha_T T+\alpha_{CO^2}\ln CO_{t-1}^2+\alpha_Y\ln Y_{t-1}+\alpha_{Y^2}\ln Y_{t-1}^2 +\alpha_C\ln C_{t-1}+\alpha_{TR}\ln TR_{t-1}+\sum_{i=1}^{p}\rho_i\Delta\ln TR_{t-i} +\sum_{j=0}^{q}\rho_j\Delta\ln CO_{t-1}^2+\sum_{k=0}^{r}\rho_k\Delta\ln Y_{t-k}+\sum_{l=0}^{s}\rho_l\Delta\ln Y_{t-1}^2 +\sum_{m=0}^{t}\rho_m\Delta\ln C_{t-m}+\mu_t \quad (9)$$

here, to test for the existence of cointegration calculated $F$-statistic is used to compare with critical bounds generated by Pesaran et al. [51]. Two critical bounds namely upper critical bound (UCB) and lower critical bound (LCB) have been developed by Pesaran et al. [51]. In our specification of Eqs. (5)–(9), the null hypothesis which is tested i.e., $H_0:\alpha_{CO^2}=\alpha_Y=\alpha_{Y^2}=\alpha_C=\alpha_{TR}=0$ against alternate hypothesis $H_0:\alpha_{CO^2}\neq\alpha_Y\neq\alpha_{Y^2}\neq\alpha_C\neq\alpha_{TR}\neq 0$ to test for cointegration. The $F$-test is non-standard and we may use the LCB and UCB developed by Pesaran et al. [51].[2] to test for cointegration. If computed $F$-statistic is more than UCB, there is cointegration between the variables. If computed $F$-statistic does not exceed the LCB, there is no cointegration relationship and if computed $F$-statistic falls between lower and upper critical bounds then decision regarding cointegration between the variables remains uncertain[3] . However, the critical bounds generated by Pesaran et al. [51] may not be appropriate for small sample like ours case with 45 observations hence, we used critical bounds developed by Narayan [52]. Further, we have conducted the stability tests to examine the stability of ARDL bounds testing estimates by utilizing CUSUM and CUSUMSQ test of (Browns et al. [53]).

[1] The ARDL approach to cointegration is applicable if variables are integrated at I(1) or I(0) or I(1)/I(0).

[2] Pesaran et al. [51] have computed two asymptotic critical values—one when the variables are assumed to be I(0) and the other when the variables are assumed to be I(1).

[3] In such case, error correction method is appropriate method to investigate the cointegration (Banerjee et al. [54]). This indicates that error correction term will be a useful way of establishing cointegration between the variables.

After confirming the evidence of cointegration and cointegration is stable we moved ahead for testing the causal relationship between the test variables in the framework of vector error correction method (VECM). The VECM in five variables case can be written as follows:

$$\Delta \ln CO_t^2 = \alpha_{01} + \sum_{i=1}^{l} \alpha_{11} \Delta \ln CO_{t-1}^2 + \sum_{j=1}^{m} \alpha_{22} \Delta \ln Y_{t-j} + \sum_{k=1}^{n} \alpha_{33} \Delta \ln Y_{t-1}^2 + \sum_{r=1}^{o} \alpha_{44} \Delta \ln C_{t-r} + \sum_{s=1}^{p} \alpha_{55} \Delta \ln TRL_{t-s} + \eta_1 ECT_{t-1} + \mu_{1i} \quad (10)$$

$$\Delta \ln Y = \beta_{01} + \sum_{i=1}^{l} \beta_{11} \Delta \ln Y_{t-i} + \sum_{j=1}^{m} \beta_{22} \Delta \ln CO_{t-1}^2 + \sum_{k=1}^{n} \beta_{33} \Delta \ln Y_{t-1}^2 + \sum_{r=1}^{o} \beta_{44} \Delta \ln C_{t-r} + \sum_{s=1}^{p} \beta_{55} \Delta \ln TR_{t-1} + \eta_2 ECT_{t-1} + \mu_{2i} \quad (11)$$

$$\Delta \ln Y_t^2 = \phi_{01} + \sum_{i=1}^{l} \phi_{11} \Delta \ln Y_{t-1}^2 + \sum_{j=1}^{m} \phi_{22} \Delta \ln CO_{t-1}^2 + \sum_{k=1}^{n} \phi_{33} \Delta \ln Y_{t-k} + \sum_{r=1}^{o} \phi_{44} \Delta \ln C_{t-1} + \sum_{s=1}^{P} \phi_{55} \Delta \ln TR_{t-1} + \eta_3 ECT_{t-1} + \mu_{3i} \quad (12)$$

$$\Delta \ln C_t = \phi_{01} + \sum_{i=1}^{l} \phi_{11} \Delta \ln C_{t-1} + \sum_{j=1}^{m} \phi_{22} \Delta \ln CO_{t-1}^2 + \sum_{k=1}^{n} \phi_{33} \Delta \ln Y_t + \sum_{r=1}^{o} \phi_{44} \Delta \ln Y_{t-1}^2 + \sum_{s=1}^{p} \phi_{55} \Delta \ln TR_{t-1} + \eta_4 ECT_{t-1} + \mu_{4i} \quad (13)$$

$$\Delta \ln TR_t = \delta_{01} + \sum_{i=1}^{l} \delta_{11} \Delta \ln TR_{t-i} + \sum_{j=1}^{m} \delta_{22} \Delta \ln CO_{t-1}^2 + \sum_{k=1}^{n} \delta_{33} \Delta \ln Y_{t-k} + \sum_{r=1}^{o} \delta_{44} \Delta \ln Y_{t-1}^2 + \sum_{s=1}^{p} \delta_{55} \Delta \ln C_{t-1} + \eta_4 ECT_{t-1} + \mu_{4i} \quad (14)$$

where $u_{it}$ are white noise residual terms. The estimates of $ECT_{t-1}$ also shows the speed of convergence from short run towards long run equilibrium path in all models depending upon the sign of the coefficient of $ECT_{t-1}$ term. The usefulness of the VECM lies in distinguishing between short-and-long runs causal relationships in one hand and detecting causality in long-run, short-run and joint i.e., short-and-long runs on the other hand. The significance of $ECT_{t-1}$ can be tested using $t$-statistic which confirms the long-run causal relationship whereas the short run causality is detected by the joint $\chi^2$ statistical significance of the estimates of first difference lagged independent variables. In the final step we used Wald-test to test the joint significance of estimates of the lagged terms of independent variables and error correction term which confirms the existence of short-and-long run causality relations (Shahbaz et al. [55]) and known as measure of strong Granger-causality (Oh and Lee [56]).

The data on these variables has been collected from World Development Indicators (CD-ROM, 2011). Further, World Development Indicates has been used to collect data on real GDP per capita, coal consumption per capita, real trade (real imports per capita + real exports per capita) per capita and $CO_2$ emissions per capita. The study covers the period of 1966–2009.

**Table 1**
Ng–Perron unit root test.

| Variables | MZa | MZt | MSB | MPT |
|---|---|---|---|---|
| **Level** | | | | |
| $\ln CO_{2t}$ | −9.8577 | −2.2095 | 0.2241 | 9.2910 |
| $\ln Y_t$ | −8.9336 | −1.8632 | 0.2085 | 11.0896 |
| $\ln Y_t^2$ | 1.2003 | 0.6869 | 0.5722 | 85.0399 |
| $\ln C_t$ | −4.1594 | −1.1484 | 0.2761 | 19.0857 |
| $\ln TR_t$ | −4.8699 | −1.4368 | 0.2950 | 18.0242 |
| 1st difference | | | | |
| $\ln CO_{2t}$ | −24.7353* | −3.5163 | 0.1421 | 3.6862 |
| $\ln Y_t$ | −19.2482** | −3.1020 | 0.1611 | 4.7358 |
| $\ln Y_t^2$ | −23.9443* | −3.4600 | 0.1445 | 3.8058 |
| $\ln C_t$ | −21.5425** | −3.2815 | 0.1523 | 4.2324 |
| $\ln TR_t$ | −22.4313* | −3.3472 | 0.1492 | 4.0729 |

* Indicate the significance at the 1% level.
** Indicate the significance at the 5% level.

## 4. Empirical results and discussions

We have applied the ARDL bounds testing approach to cointegration to find long run relationship between economic growth, coal consumption, trade openness and $CO_2$ emissions in case of India. Although bounds testing approach is flexible regarding the integrating order of the variables. We can apply it, if the variables are integrated at I(0), I(1) or I(0)/I(1). We cannot compute the ARDL $F$-statistics for long run relationship if any variable is found to be stationary at I(2). To ensure that none of the variables is stationary at I(2) or beyond that order of integration, we applied Ng–Perron [57] unit root test. The results are reported in Table 1. This empirical evidence indicates that all the series have unit root at their level form but found to be stationary at 1st difference. This shows that all the variables have I(1) order of integration. The empirical evidence provided by Ng–Perron may be biased because it does not have information about structural break stemming in the series.

To solve this issue, we applied unit root test with two structural breaks developed by Narayan and Popp [49]. The inappropriate chose of structural breaks may reject null hypothesis and provide inconclusive results. The technique used in N–P unit root test allows in determining two structural breaks in the level and trend of the series endogenously. The unit root test developed by Narayan and Popp [49] indicates two structural breaks efficiently as compared to other structural break unit root tests. Table 2 reported the results by Narayan and Popp [49] unit root test. Our empirical exercise reveals that all the variables are found to be non-stationary (except $\ln TR_t$, which is in model 2 turns to be stationary) at level but integrated at 1st difference. This confirms that all the variables are integrated at I(1) and robust[4].

Our empirical evidence confirms that all the variables are stationary at 1st difference form that intends to apply the ARDL bounds approach in examining the long run relationship between the series. It is prerequisite to choose appropriate lag length of the variables to capture the dynamic relationship between the variables. The statistics of $F$-test are very much elusive with the selection of lag order of the variables. Inappropriate lag length selection provides biased results and in resulting, decision about cointegration is worthless (Lütkepohl [58]). We have used AIC and SBC criterion to choose lag order but our decision is based minimum value of AIC. Lütkepohl [58] suggested that lag order selected by AIC provides efficient and consistent results. The

[4] The results of N–P at 1st difference are not provided here due lack of space and are available from authors upon request.

**Table 2**
Narayan and Popp [49] Structural Break Unit Root Test.

| Variable | Model 1(M1) | | | Model 2(M2) | | |
|---|---|---|---|---|---|---|
| | *T*-statistic | TB1 | TB2 | *T*-statistic | TB1 | TB2 |
| $\ln CO_{2t}$ | −4.0378 | 1976 | 2000 | −4.3381 | 1976 | 2000 |
| $\ln Y_t$ | 0.7720 | 1974 | 1978 | 0.4483 | 1974 | 1978 |
| $\ln Y_t^2$ | 1.0668 | 1974 | 1978 | 0.7999 | 1974 | 1978 |
| $\ln C_t$ | −1.1955 | 1973 | 1989 | −1.6512 | 1977 | 1989 |
| $\ln TR_t$ | −3.0225 | 1974 | 1981 | −5.3848** | 1984 | 1994 |

*Note*: Model-1 assumes two breaks in level and Model-2 assumes two breaks in level as well as slope.

** Denotes significance at 5% level.

**Table 3**
Results of ARDL cointegration test.

| Variable | $\ln CO_{2t}$ | $\ln Y_t$ | $\ln Y_t^2$ | $\ln C_t$ | $\ln TR_t$ |
|---|---|---|---|---|---|
| *F*-statistics | 8.9129** | 7.1597*** | 7.1578*** | 7.4063*** | 5.3858 |
| Critical values# | 1% level | 5% level | 10% level* | | |
| Lower bounds | 10.150 | 7.135 | 5.950 | | |
| Upper bounds | 11.130 | 7.980 | 6.680 | | |
| Diagnostic tests | | | | | |
| $R^2$ | 0.8325 | 0.9994 | 0.9995 | 0.6249 | 0.8018 |
| $Adj{-}R^2$ | 0.6802 | 0.9990 | 0.9991 | 0.3796 | 0.6037 |
| Durbin–Watson | 1.6951 | 2.2267 | 2.2155 | 2.0707 | 2.3233 |

# Critical values bounds are from Narayan [52] with unrestricted intercept and unrestricted trend.

* Show the significance at 1% level.

** Show the significance at 5% level.

*** Show the significance at 10% level.

**Table 4**
Results of Johansen cointegration test.

| Hypothesis | Trace statistic | Maximum eigen value |
|---|---|---|
| $R=0$ | 105.8022* | 46.7978* |
| $R\le 1$ | 59.0044* | 32.3417** |
| $R\le 2$ | 26.6626 | 17.6688 |
| $R\le 3$ | 8.9938 | 8.6642 |
| $R\le 4$ | 0.3295 | 0.3295 |

* Show significant at 1% level.

** Show significant at 5% level.

reason is that AIC has superior properties and high explaining power as compared to SBC. Our empirical evidence shows that we cannot take lag more than 2 because data sample consists of 45 years Table 3. We have used yearly data over the period of 1966–2009 of Indian economy[5].

After choosing lag order, next step is to compare our computed *F*-statistics with lower and upper critical bounds generated by Narayan [52]. The results show that our calculated *F*-statistics exceed upper critical bounds at 5% and 10% levels, respectively, once, $CO_2$ emissions per capita, real GDP per capita (squared of real GDP per capita) and coal consumption per capita treated as respond variables. The results are reported in Table 4.

This implies that three cointegrating vectors are found recommending the long run relationship between coal consumption, economic growth, trade openness and $CO_2$ emissions in case of India over the study period of 1966–2011.

The robustness of long run results established by the ARDL bounds testing approach to cointegration is tested by applying

**Table 5**
Long-and-short run analysis.

| **Dependent variable** $=\ln CO_{2t}$ | | | |
|---|---|---|---|
| **Long run results** | | | |
| **Variable** | Coefficient | Std. Error | *T*-Statistic |
| **Constant** | −50.2450 | 4.7539 | −10.5692* |
| $\ln Y_t$ | 10.0674 | 0.8740 | 11.5182* |
| $\ln Y_t^2$ | −0.4942 | 0.0410 | −12.0467* |
| $\ln C_t$ | 0.8436 | 0.0999 | 8.43771* |
| $\ln T_{Rt}$ | 0.0862 | 0.0415 | 2.07734** |
| **Short run results** | | | |
| **Constant** | 0.0282 | 0.0055 | 5.0598* |
| $\ln Y_t$ | 4.9768 | 1.6149 | 3.0816* |
| $\ln Y_t^2$ | −0.2392 | 0.0807 | −2.9622* |
| $\ln C_t$ | 0.4481 | 0.0948 | 4.7244* |
| $\ln T_{Rt}$ | −0.1090 | 0.0453 | −2.4035** |
| $ECM_{t-1}$ | −0.2994 | 0.0948 | −3.1574* |
| Diagnostic tests | | | |
| Test | *F*-statistic | Prob. value | |
| $\chi^2 NORMAL$ | 0.8323 | 0.6595 | |
| $\chi^2 SERIAL$ | 1.9906 | 0.1548 | |
| $\chi^2 ARCH$ | 0.0150 | 0.9030 | |
| $\chi^2 WHITE$ | 0.7055 | 0.7110 | |
| $\chi^2 REMSAY$ | 2.3963 | 0.1321 | |

* Denote the significant at 1% level.

** Denote the significant at 5% level.

Johansen multivariate cointegration approach. The results reported in Table 4 confirm that there are two cointegrating vectors at 1% level of significance indicated both by Trace statistic and Maximum Eigen values. This corroborates the long run relationship between coal consumption, economic growth, trade openness and $CO_2$ emissions in case of India over the study period of 1966–2011.

After investigating the robustness of long run relationship between these variables, the long run marginal impacts of coal consumption, economic growth, trade openness on $CO_2$ emissions in case of India is investigated by applying OLS approach. The results reported in Table 5 postulated that coal consumption is major contributor to energy pollutants and it is statistically significant at 1% level of significance. A 1% rise in $CO_2$ emissions is associated with 0.8436% consumption of coal. These findings support to the view by Wolde-Rufael [59] that coal consumption highly contributes to energy pollutants as compared to other indictors of energy. Jayanthakumaran et al. [47] also nominated that India meets 55% of energy demand through coal consumption and produces 5% of $CO_2$ emissions of the world[6]. Furthermore, Jayanthakumaran et al. [47] reported that in total energy emissions 86% is contributed by coal consumption in case of India and same inference drawn by Alam et al. [60],[7] .

The impact of trade openness on energy emissions is positive and significant at 5% level. All else is same, a 1% expansion in trade openness leads to upsurge in energy emissions by 0.0862%. This finding is consistent with Jayanthakumaran et al. [47] also reported positive effect of international trade on $CO_2$ emissions but it is statistically insignificant. In regional studies, Halicioglu [46] reported that international trade increases energy emissions by raising economic growth and same inference is drawn by Nasir and Rehman [36] in case of Turkey and Pakistan, respectively. On contrary, Shahbaz et al. [37] noted that trade openness improves the environmental quality by enhancing the capacity of country

[5] Results of lag length selection are available from authors upon request.

[6] Other sources of energy such as crude oil, natural gas and petroleum products are used to meet the rest 45% energy demand.

[7] Alam et al. [60] used total primary consumption as an indicator of energy.

**Table 6**
VECM Granger causality analysis.

| Dependent variables | Direction of causality | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Short run** | | | | | **Long run** | **Joint (Long-and-short runs) causality** | | | | |
| | $\ln CO_{2t}$ | $\ln Y_t$ | $\ln Y_t^2$ | $\ln C_t$ | $\ln T_{Rt}$ | $ECT_{t-1}$ | $\ln CO_{2t}, ECT_{t-1}$ | $\ln Y_t, ECT_{t-1}$ | $\ln Y_t^2, ECT_{t-1}$ | $\ln C_t, ECT_{t-1}$ | $\ln T_{Rt}, ECT_{t-1}$ |
| $\ln CO_{2t}$ | – | 3.6272** [0.0384] | 3.3713** [0.0473] | 12.8363* [0.0001] | 5.1278** [0.0119] | −0.4550* [−3.9339] | – | 7.5935* [0.0006] | 6.9193* [0.0040] | 9.3793* [0.0001] | 7.8799* [0.0005] |
| < **mmEquation id=”eqn87” /** > | 4.6517** [0.0174] | – | 8.1920** [0.0000] | 1.5550 [0.2227] | 6.1098* [0.0060] | −0.1632*** [−1.8427] | 3.4984** [0.0274] | – | 5.8590* [0.0019] | 1.2920 [0.2952] | 4.5041** [0.0101] |
| $\ln Y_t^2$ | 4.2919* [0.432] | 8.4460* [0.0001] | – | 0.9678 [0.3878] | 5.8392* [0.0072] | −0.1535*** [−1.7716] | 3.1922** [0.0377] | 6.0750* [0.0045] | – | 1.1602 [0.3412] | 4.3125** [0.0121] |
| $\ln C_t$ | 12.5233* [0.0001] | 0.5701 [0.5715] | 0.5177 [0.6013] | – | 2.7016* [0.0834] | −0.7704* [−4.2526] | 10.0023* [0.0001] | 6.5615* [0.0015] | 6.6326* [0.0012] | – | 7.2152* [0.0009] |
| $\ln T_{Rt}$ | 2.4178*** [0.1078] | 4.6856** [0.0169] | 4.5034** [0.0195] | 1.0847 [0.3509] | – | – | – | – | – | – | – |

* Show significant at 1% level.
** Show significant at 5% level.
*** Show significant at 10%,.level in parenthesis we reported p-values.

to implement advanced technology to increase domestic production.

The impact of linear and nonlinear terms of real GDP per capita is positive and negative. The coefficients of linear and nonlinear terms are 10.0674 and −0.4942 and it is statistically significant at 1% level of significance, respectively. The significance of both linear and non-linear terms of real GDP per capita provides the empirical evidence of inverted-U shaped relationship between economic growth and $CO_2$ emissions “so called environmental Kuznets curve” (EKC). The empirical exercise revealed that a 10.0674% energy emissions are linked with 1% increase in GDP per capita and inverse effect of squared term of real GDP per capita shows the delinking point of $CO_2$ emissions i.e., −0.4942 and real GDP per capita, once an economy achieves higher level of income. This empirical evidence provides the support for EKC revealing that $CO_2$ emissions increase at the initial stage of economic growth and decline after a threshold point i.e., Ind. Rupee 28,131 (US$531). These results are with existing literature such as He [61], Song et al. [6], Jalil and Mahmud [20], Fodha and Zaghdoud [22] and Jayanthakumaran et al. [47] for China and India, Halicioglu [46] for Turkey, Lean and Smyth [28] for ASEAN countries, Nasir and Rehman [36] and Shahbaz et al. [37] for Pakistan. Saboori et al. [65] for Malaysia and Shahbaz et al. [68] for Romania.

The short run dynamics are also reported in lower segment of Table 6 and the results indicated that coal consumption is also main contributor to $CO_2$ emissions and it is statistically significant at 1% level. Interestingly, international trade reduces energy emissions significantly at 5% significance level. The coefficients of linear term of real GDP per capita and nonlinear i.e., squared term of real GDP per capita are positive and negative, respectively. These estimates are significant at 1% significance level. This further confirms the existence of EKC in case of India. The short run estimates are less than long run estimates which indicates the reliability and stability of estimated results.

The estimated coefficient of the lagged ECM term is −0.2994 and significant at the 1% level. This establishes long run relationship among the running variables. This suggests that changes in $CO_2$ emissions from the short run to the long run are corrected by 29.94% each year. The significance of lagged error correction term further confirms our established long run relationship between coal consumption, economic growth, trade openness and $CO_2$ emissions.

The diagnostics tests such as LM test for serial correlation, normality of residual term and white heteroscedisticity test for short run model are reported in Table 5. The findings suggest that

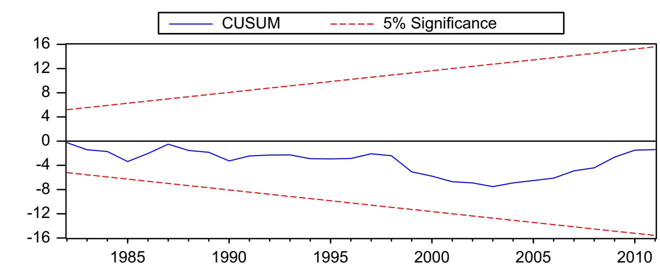


**Fig. 3. Plot of cumulative sum of recursive residuals**. The straight lines represent critical bounds at 5% significance level.

the short-run model passes all diagnostic tests successfully. The evidence indicates that error term is normally distributed and there is an absence of serial correlation. There is no evidence of autoregressive conditional heteroscedisticity and same inference for white heteroscedisticity. The short run model has passed Remsay reset test which confirms that the functional form of short run model is correctly specified.

It is suggested by Browns et al. [53] that stability of long run and short run parameters can be tested by applying CUSUM and CUSUMsq tests. In doing so, the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMsq) tests have been employed for parameter stability.

The results are shown in Figs. 3 and 4. The graph should lie within the appropriate bounds if the parameters are stable (Pesaran et al. [51]). The graph of CUSUM at the 5% level and we can claim the stability of long-and-short runs parameters.

### 4.1. The VECM Granger causality analysis

The presence of cointegration among the variables implies that causality relation must be existed at least from one side. The directional relationship between coal consumption, economic growth, international trade and $CO_2$ emissions will provide help in articulating comprehensive policy to economic growth by controlling environment from degradation and utilize energy efficient technologies importing from advanced countries. We applied Granger causality test within the VECM framework to detect the causality between the variables. Table 6 reports the results of the VECM Granger causality analysis. The long run causality is captured by a significant $t$-test on a negative coefficient of the lagged error–correction term $ECM_{t-1}$. The jointly

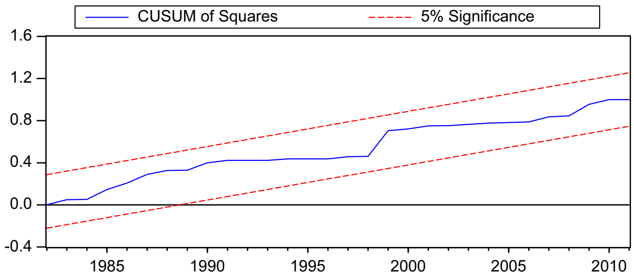


**Fig. 4. Plot of cumulative sum of squares of recursive residuals**. The straight lines represent critical bounds at 5% significance level.

significant LR test on the lagged explanatory variables shows short-run causality.

In long run, our empirical evidence reports bidirectional causality relationship between income and $CO_2$ emissions. The feedback hypothesis exists between coal consumption and $CO_2$ emissions. Coal consumption and economic growth Granger cause each other. This finding is contradictory with Li and Li [62] who reported that coal consumption Granger causes economic growth while consistent with Paul and Bhattacharya [63] showed feedback between energy consumption and economic growth. This suggests that government should encourage energy exploration polices which in resulting spur economic growth and hence demand for energy. There is bidirectional causal relationship between economic growth and $CO_2$ emissions. These findings confirm our long run as well short run results that income has positive and negative effects on $CO_2$ emissions. This further validates the existence of environmental Kuznets curve (EKC). On contrary, Ghosh [26] and Alam et al. [60] presented no causal relationship between income and $CO_2$ emissions.

This shows the significance of our empirical evidence as we applied more specified economic model. Trade openness Granger causes economic growth, coal consumption and $CO_2$ emissions. This implies that trade openness stimulates economic activity and adds in energy demand (coal consumption) which emits $CO_2$ emissions. In short run, bidirectional causality is found between economic growth and $CO_2$ emissions, coal consumption and $CO_2$ emissions, trade openness and $CO_2$ emissions. The findings indicated that the long run income elasticity for $CO_2$ emissions is less than the short run elasticity is further evidence for an EKC (see Narayan and Narayan [30] for more). The feedback hypothesis also exists between trade and economic growth. The unidirectional causal relationship is found running from trade openness to coal consumption and no causality exists between coal consumption and economic growth. The results of joint causality confirm the long-and-short runs findings.

## 5. Conclusion and policy implications

This paper investigated the dynamic linkages between coal consumption, economic growth, trade openness and $CO_2$ emissions in case of India over the period of 1966–2011. We have applied Ng–Perron [57] unit root test to test stationarity of the variables and Narayan and Popp [49] is accompanied to examine the robustness of empirical evidence. Further, the ARDL bounds testing approach to cointegration has employed to investigated the long run relationship between the variables and Johansen multivariate cointegration is applied to test the strength of long run results. The present study has important policy implications for Indian economy. The empirical evidence of strong relationship between coal consumption and economic growth indicates that sustained level of economic growth can be achieved by exploring the new sources of energy supply for long span of time.

Our results confirmed that all the variables are cointegrated for long run relationship and long run results are robust. Coal consumption is main contributor to $CO_2$ emissions. A rise in economic growth raises demand for coal that emits energy pollutants. Trade openness is also positively linked with $CO_2$ emissions but in short run former declines later. Results also validated the existence of environmental Kuznets curve (EKC) in long run as well as in short run in case of India. The causality analysis explored the bidirectional causal relationship between economic growth and $CO_2$ emissions and feedback hypothesis exists between coal consumption and $CO_2$ emissions. Coal consumption and economic growth Granger cause each other. Trade openness Granger causes economic growth, coal consumption and $CO_2$ emissions. Economic growth and $CO_2$ emissions Granger cause trade openness in short run.

Hence, our results shows that dependence on the coal consumption as a factor that promotes economic growth might be feasible option for short run but in the long run we have to look for alternative of this. This is particularly because coal consumption increases $CO_2$ emissions and which indirectly has negative impact on the economic growth. The other interesting issues are the Granger-causal relationship between $CO_2$ emissions, trade openness, and coal consumption. Since trade openness is found to Granger-cause $CO_2$ emissions, we can suggest Indian policymakers on a few important points: (1) allowance of foreign investors to invest in the India particularly in know-how and advanced technologies (2) free entry of FDI because when FDI flows into a host country, FDI may transfer new ideas, technologies and managerial skills to domestic firms and which in turn expected to reduce $CO_2$ emissions (3) promotion of such activities through which foreign firms may provide continuous technological assistance, such as introduction of new technologies and training of workers, to the domestic firms which will lead to decrease in $CO_2$ emission in one hand and increase economic growth on the other. These processes are also expected to reduce dependence on the consumption of coal without harming the interest of higher economic growth.

## References

[1] Boehmer-Christiansen S. Global climate protection policy: the limits of scientific advice. Global Environmental Change 1994;4:140–59.
[2] Grossman GM, Krueger AB Environmental impacts of a North American free trade agreement. NBER working paper, no. 3914, Washington; 1991.
[3] Grossman GM, Krueger AB. Economic growth and the environment. Quarterly Journal of Economics 1995;110:353–77.
[4] Shafik N, Bandyopadhyay S Economic growth and environmental quality: time series and cross country evidence. World development working paper WPS 904. Washington, DC: World Bank; 1992.
[5] Panayotou T Empirical tests and policy analysis of environmental degradation at different stages of economic development. Working paper WP238, technology and employment programme. Geneva: International Labor Office; 1993.
[6] Song T, Zheng T, Tong L. An empirical test of the environmental Kuznets curve in China: a panel cointegration approach. China Economic Review 2008;19:381–92.
[7] Stern DI. The rise and fall of the environmental Kuznets curve. World Development 2004;32:1419–39.
[8] Stokey NL. Are there limits to growth? International Economic Review 1998;39:1–31.
[9] Lopez R. The environment as a factor of production: the effects of economic growth and trade liberalization. Journal of Environmental Economics and Management 1994;27:163–84.
[10] Andreoni J, Levinson A. The simple analytics of the environmental Kuznets curve. Journal of Public Economics 2001;80:269–86.
[11] Suri V, Chapman D. Economic growth, trade and the energy: implications for the environmental Kuznets curve. Ecological Economics 1998;25:195–208.
[12] Lucas G, Wheeler N, Hettige R The inflexion point of manufacture industries: international trade and environment. World Bank discussion paper, no. 148, Washington; 1992.

[13] Wyckoff AW, Roop JM. The embodiment of carbon in imports of manufactured products: implications for international agreements on greenhouse gas emissions. Energy Policy 1994;22:187–94.
[14] Heil MT, Selden TM. Panel stationarity with structural breaks: carbon emissions and GDP. Applied Economics Letters 1999;6:223–5.
[15] Friedl B, Getzner M. Determinants of $CO_2$ emissions in a small open economy. Ecological Economics 2003;45:133–48.
[16] Nohman A, Antrobus G. Trade and the environmental Kuznets curve: is Southern Africa a pollution heaven? South African Journal of Economics 2005;73:803–14.
[17] Dinda S, Coondoo D. Income and emission: a panel data-based cointegration analysis. Ecological Economics 2006;57:167–81.
[18] Coondoo D, Dinda S. The carbon dioxide emission and income: a temporal analysis of cross-country distributional patterns. Ecological Economics 2008;65:375–85.
[19] Dhakal S. Urban energy use and carbon emissions from cities in China and policy implications. Energy Policy 2009;37:4208–19.
[20] Jalil A, Mahmud S. Environment Kuznets curve for $CO_2$ emissions: a cointegration analysis for China. Energy Policy 2009;37:5167–72.
[21] Zhang XP, Cheng XM. Energy consumption, carbon emissions and economic growth in China. Ecological Economics 2009;68:2706–12.
[22] Fodha M, Zaghdoud O. Economic growth and pollutant emissions in Tunisia: an empirical analysis of the environmental Kuznets curve. Energy Policy 2010;38:1150–6.
[23] Akbostancl E, Türüt-Aslk S, Ipek TG. The relationship between income and environment in Turkey: is there an environmental Kuznets curve? Energy Policy 2009;37:861–7.
[24] Ang JB. $CO_2$ emissions, energy consumption, and output in France. Energy Policy 2007;35:4772–8.
[25] Ang JB. Economic development, pollutant emissions and energy consumption in Malaysia. Journal of Policy Modeling 2008;30:271–8.
[26] Ghosh S. Examining carbon emissions-economic growth nexus for India: a multivariate cointegration approach. Energy Policy 2010;38:2613–3130.
[27] Apergis N, Payne JE. Energy consumption and economic growth: evidence from the commonwealth of independent states. Energy Economics 2009;31:641–7.
[28] Lean HH, Smyth R. $CO_2$ emissions, electricity consumption and output in ASEAN. Applied Energy 2010;87:1858–64.
[29] Apergis N, Payne JE. The emissions, energy consumption, and growth nexus: evidence from the commonwealth of independent states. Energy Policy 2010;38:650–5.
[30] Narayan PK, Narayan S. Carbon dioxide emissions and economic growth: panel data evidence from developing countries. Energy Policy 2010;38:661–6.
[31] Chen S. Engine or drag: can high energy consumption and $CO_2$ emission derive the sustainable development of Chinese industry. Frontiers of Economic in China 2009;4:548–71.
[32] Shiyi C. Engine or drag: can high energy consumption and $CO_2$ emission derive the sustainable development of Chinese industry. Frontiers of Economic in China 2009;4:548–71.
[33] Pao HT, Tsai CM. $CO_2$ emissions, energy consumption and economic growth in BRIC countries. Energy Policy 2010;38:7850–60.
[34] Ozturk I, Acaravci A. $CO_2$ emissions, energy consumption and economic growth in Turkey. Renewable and Sustainable Energy Reviews 2010;14:3220–5.
[35] Acaravci A, Ozturk I. On the relationship between energy consumption, $CO_2$ emissions and economic growth in Europe. Energy 2010;35:5412–20.
[36] Nasir M, Rehman FU. Environmental Kuznets curve for carbon emissions in Pakistan: an empirical investigation. Energy Policy 2011;39:1857–64.
[37] Shahbaz M, Lean HH, Shabbir MS. Environmental Kuznets curve hypothesis in Pakistan: cointegration and Granger causality. Renewable and Sustainable Energy Reviews 2012;16:2947–53.
[38] Iwata H, Okada K, Samreth S. A note on the environmental Kuznets curve for $CO_2$: a pooled mean group approach. Applied Energy 2011;88:1986–96.
[39] Runge CF. Freer trade, protected environment: balancing trade liberalization with environmental interests. Council on Foreign Relations Books; 1994.
[40] Helpman E. Explaining the structure of foreign trade: where do we stand? Review of World Economics 1998;134:573–89.
[41] Schmalensee R, Stoker TM, Judson RA. World carbon dioxide emissions: 1950–2050. The Review of Economics and Statistics 1998;80:15–27.
[42] Copeland B, Taylor MS International trade and the environment: a framework for analysis, NBER working paper, no. 8540, Washington; 2001.
[43] Chaudhuri S, Pfaff A Economic growth and the environment: what can we learn from household data? Working paper, Columbia University, USA; 2002.
[44] Machado GV Energy use, $CO_2$ emissions and foreign trade: an IO approach applied to the Brazilian case. Thirteenth international conference on input–output techniques, Macerata, Italy; (2000), 21–25 Aug.
[45] Mongelli I, Tassielli G, Notarnicola B. Global warming agreements, international trade and **energy/carbon embodiments: an input–output approach to the Italian case. Energy Policy 2006;34:88–100.
[46] Halicioglu F. An econometric study of $CO_2$ emissions, energy consumption, income and foreign trade in Turkey. Energy Policy 2009;37:1156–64.
[47] Jayanthakumaran K, Verma R, Liu Y. $CO_2$ emissions energy consumption, trade and income: a comparative analysis of China and India. Energy Policy 2012;42:450–60.
[48] Soytas U, Sari U, Ewing BT. Energy consumption, income and carbon emissions in the United States. Ecological Economics 2007;62:482–9.
[49] Narayan PK, Popp S. A new unit root test with two structural breaks in level and slope at unknown time. Journal of Applied Statistics 2010;37:1425–38.
[50] Pesaran MH, Shin Y. An autoregressive distributed lag modeling approach to cointegration analysis. Chapter 11. In: Strom S, editor. Econometrics and economic theory in the 20th century: the Ragnar Frisch centennial symposium. Cambridge: Cambridge University Press; 1999.
[51] Pesaran MH, Shin Y, Smith RJ. Bounds testing approaches to the analysis of level relationships. Journal of Applied Econometrics 2001;16:289–326.
[52] Narayan PK. The saving and investment nexus for China: evidence from cointegration tests. Applied Economics 2005;37:1979–90.
[53] Browns RL, Durbin J, Ewans JM. Techniques for testing the constance of regression relations overtime. Journal of Royal Statistical Society 1975;37:149–72.
[54] Banerjee A, Dolado JJ, Mestre R. Error–correction mechanism tests for cointegration in a single-equation framework. Journal of Time Series Analysis 1998;19:267–83.
[55] Shahbaz M, Tang CF, Shabbir MS. Electricity consumption and economic growth nexus in Portugal using cointegration and causality approaches. Energy Policy 2011;39:3529–36.
[56] Oh W, Lee K. Causal relationship between energy consumption and GDP revisited: the case of Korea 1970–1999. Energy Economics 2004;26:51–9.
[57] Ng S, Perron P. Lag length selection and the construction of unit root test with good size and power. Econometrica 2001;69:1519–54.
[58] Lütkepohl H. Structural vector autoregressive analysis for cointegrated variables. AStA Advances in Statistical Analysis 2006;90:75–88.
[59] Wolde-Rufael Y. Coal consumption and economic growth revisited. Applied Energy 2010;87:160–7.
[60] Alam MJ, Begum IA, Buysse J, Rahman S, Huylenbroeck GV. Dynamic modeling of causal relationship between energy consumption, $CO_2$ emissions and economic growth in India. Renewable and Sustainable Energy Reviews 2011;15:3243–51.
[61] He J. China's industrial SO2 emissions and its economic determinants: EKC's reduced vs. structural model and the role of international trade. Environment and Development Economics 2008;14:227–62.
[62] Li J, Li ZA. Causality analysis of coal consumption and economic growth for China and India. Natural Resources 2011;2:54–60.
[63] Paul S, Bhattacharya RN. Causality between energy consumption and economic growth in India: a note on conflicting results. Energy Economics 2004;26:977–83.
[64] Saboori B, Sulaiman JB, Mohd S. An empirical analysis of the environmental Kuznets curve for $CO_2$ emissions in Indonesia: the role of energy consumption and foreign trade. International Journal of Economics and Finance 2011;4:243–51.
[65] Saboori B, Sulaiman JB, Mohd S. Economic growth and $CO_2$ emissions in Malaysia: a cointegration analysis of the environmental Kuznets curve. Energy Policy 2012. http://dx.doi.org/10.1016/j.enpol.2012.08.065.
[66] Tiwari AK. Energy consumption, $CO_2$ emissions and economic growth: evidence from India. Journal of International Business and Economy 2011;**12**:85–122.
[67] Yeh CC, The relationships between the $CO_2$ emissions and national income under quantiles inference. Asian Journal of Natural & Applied Sciences; 1:55–66.
[68] Shahbaz M, Mutascu M, Azim P. Environmental Kuznets Curve in Romania and the Role of Energy Consumption. Renewable and Sustainable Energy Reviews 2013; 18: 165–173.
[69] Hwang JH, Yoo SH. Energy consumption, $CO_2$ emissions, and economic growth: evidence from Indonesia. Quality & Quantity 2012. http://dx.doi.org/10.1007/s11135-012-9749-5.
[70] Uddin MGS, Bidisha SH, Ozturk I. Carbon emissions, energy consumption and economic growth relationship in Sri Lanka. Energy Sources, Part B: Economics, Planning, and Policy 2013. http://dx.doi.org/10.1016/j.ecosys.2011.10.005.
[71] http://www.indianexpress.com/news/indias-provisional-co2-cut-target-at-24-pct-by-2020/548995.